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DESIGNING FOR SUSTAINABLE DEVELOPMENT – THE CASE OF THE SOLAR POWERED WATER PUMP

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ABSTRACT
To some engineers, Sustainable Development implies developing countries, small scale manufacture, low skill input, water supply and so on. To others, Sustainable Development is about emissions, global warming and environmental concerns. It is often unclear as to specifically what "Design for Sustainable Development" is addressing.
The solar (photovoltaic) powered water pump might be thought of as an example of Design for Sustainable Development in the developing country context. Over the last twenty five years, much has been written about such pumps. Clean water for all has been promised at minimal cost, particularly with projected reductions in price of photovoltaic panels. Unfortunately, whilst some projects have proved particularly successful, there are still many voices of doubt, questioning whether photovoltaic based water pumping systems can ever be "Appropriate Technology".
This paper therefore investigates Design for Sustainable Development, using the role of the solar powered water pump in development as an example. In doing so, it provides an understanding of Sustainable Development and Appropriate Technology, and what this implies for any design process that aims to incorporate Design for Sustainable Development, irrespective of global location, North or South.

Keywords: Design for Sustainability; Sustainable Development; Appropriate Technology; Solar Powered Water Pumps

1 INTRODUCTION
The engineering design process has traditionally been linked with trade-offs, such as between price and functionality, safety and aesthetics, life span and maintenance. In recent years, however, a further constraint has been introduced – that of "sustainability" or "sustainable development" [1]. With increasing legislative input, the engineering designer must now consider the effects of the product on the environment. For this reason a number of "Design for Sustainable Development" or "Design for Environment" methodologies have begun to spring up. The most widely quoted of these, perhaps, is Life Cycle Analysis with its own International Standard [2]. This paper will examine what it means to be "sustainable" and will provide an in-depth analysis of Sustainability and "Appropriate Technology" to see what these imply about the design process.
Design for Sustainable Development (DFSD) is often taken by different designers to mean different things. Some engineering designers think of DFSD as a tool along the lines of Design for Assembly (DFA) – unfortunately where DFA has been shown [3, 4] to bring significant financial rewards if used appropriately within the design process, DFSD is often thought of as an altruistic goal, a promotional tool, or a legalistic requirement. Some companies with a genuine philanthropic bent have naturally included DFSD as an everyday "way of thinking" that defines how they go about their work and thence defines their products; Brundtland recognises this need for taking DFSD into account, stating "the responsible manager has the desire to look ahead with a perspective going beyond [their] present individual tenures" [5]. Other companies use DFSD for promotional purposes, to make them appear more "green", thereby making their products more favourable to consumers. The line between these two can be extremely fine with Corporate Social Responsibility (CSR) statements. Taking 3M as an example, they are highly regarded as being a "sustainable" company [6], and currently lead the Dow Jones Sustainability Index [7] in their product sector. A cynic, however, may suggest that their CSR statement [8] is nothing more than a means of self-promotion and an attempt to gain market-share.

A further reason for using DFSD might be in response to legal requirements – requirements to phase out the use of certain substances [9], or to increase the recycling of components [10].

To other design engineers, DFSD implies the design of systems directly relevant to developing countries – the “South”. These systems may be water or energy related, or may be low in skill and high in labour requirements – they might be “appropriate” to the environment in which they are to be used.

The solar (photovoltaic) powered water pump (“PVP”, an example of which can be seen in Figure 1) seems to fit somewhere in between these two different definitions of DFSD – the Northern and the Southern versions. It uses photovoltaics and sometimes highly complex electronic control systems – systems found as standard in the North. At the same time, it addresses the basic need for water in the South. This paper therefore investigates the PVP as an example of holistic, non-location specific DFSD in practice. It considers definitions and implications of “Sustainable Development” and “Appropriate Technology” and whether the PVP can fit in with either. In doing so, the paper highlights a number of issues surrounding DFSD and DFSD methodologies that must be taken into account by all engineering designers, in the North or in the South.

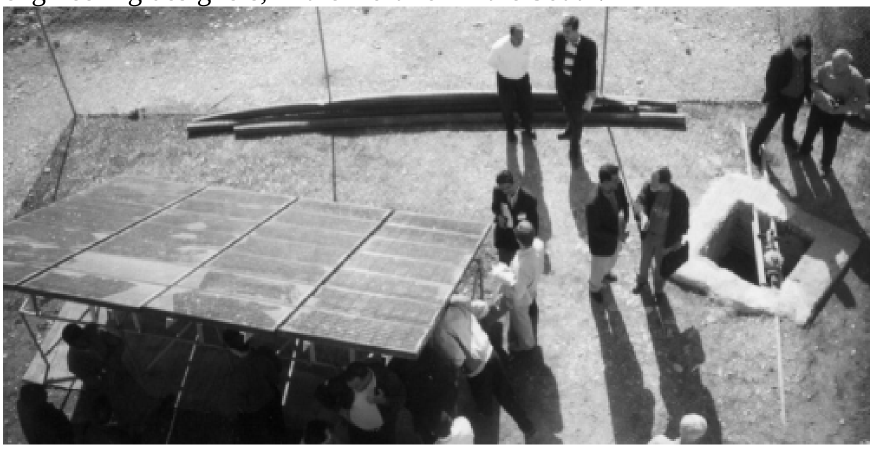

Figure 1. PVP System in Morocco

2 SUSTAINABLE DEVELOPMENT AND APPROPRIATE TECHNOLOGY

In order to understand Design for Sustainable Development, it is clearly important that Sustainable Development itself is first fully understood.

Hazeltine and Bull state that ‘the program for meeting material needs must be “sustainable”’ [11] and then use a number of examples to try to explain the meaning of sustainability. Perhaps better than using examples, however, is the definition of Sustainable Development provided in 1987 by the UN commissioned “Brundtland report” [12]: “meeting the needs and aspirations of the present without compromising the ability to meet those of the future”.

Such a definition raises two separate issues: the ability to meet one’s own “needs and aspirations”, to sustain oneself today; and the reduction of impact on the future [13]. In raising the two issues, the distinction between DFSD in the North and in the South can immediately be seen; the former issue is typical for South-focused DFSD but forgotten in the North. In the North, the emphasis is often on the future – it is implicit that the “needs and aspirations of the present” will be met. The recent Stern Review [14] is a prime example of looking to the future and the potential impacts of climate change on the world economy. On those occasions, however, where the “needs and aspirations” are the survival of the company (“industrial sustainability” [13]), the future tends to be ignored as being too far away and the company thereby falls out of the “Sustainable Development” discussion. In the South the emphasis is quite clearly on the here and now, providing water, energy, sanitation and so on, but increasingly is bearing in mind the future – Sir Nicholas Stern notes that “developing countries must take significant action too” [14] for the prevention of climate change.

Evidently, both the present and the future need consideration; without the first, the second is meaningless as there will be no-one to enjoy the future! Hazeltine and Bull reinforce this, stating that “One must look at what one is trying to accomplish, what expertise and resource are available, and what unintended consequences may ensue” [11]; “One must look at what one is trying to accomplish” – i.e. “the needs and aspirations of today” – “… and what unintended consequence may ensue” – i.e.

"without compromising the ability to meet those of the future". Thus any engineering design process that purports to address Sustainable Development, whether North- or South-orientated, must place equal weight on both present requirements and future concerns.

Moving on to Appropriate Technology and, in particular, its links with Sustainable Development, Professor P. D. Dunn [15] summarises Appropriate Technology, stating the principal aims of development as:

(1) To improve the quality of life of the people.
(2) To maximise the use of renewable resources.
(3) To create work places where the people now live.

Whilst it is widely assumed that "development" in this context refers to the South, it can equally be applicable to the North and indeed Dunn's aims can be seen to be consistent with many current practices. Using the north-east of England as an example, the local "Regional Development Agency" is One NorthEast. Their mission statement [16] includes the following:

The Agency is harnessing all the physical and human resources of the region, in both rural and urban communities, to:

- *Accelerate economic development and regeneration*
- *Promote business growth and efficiency, boost investment and increase competitiveness*
- *Generate thousands of new jobs*
- *Develop the work skills of the people living here to meet the needs of a changing economy*

If the UK Government's drive for renewable energy is further factored in, Dunn's aims for development can be seen not only to be relevant in the South, but also to be reflected in Northern governmental policies.

Dunn goes beyond these aims, however, by suggesting [15] that any technology used should:

(a) Employ local skills.
(b) Employ local material resources.
(c) Employ local financial resources.
(d) Be compatible with local culture and practices.
(e) Satisfy local wishes and needs.

For technology to be deemed "Appropriate", it must first relate to aims (1) to (3), then satisfy criteria (a) to (e). None of these might be earth shattering in their novelty, yet they are routinely ignored in the application of technology.

The US Congress's Office of Technology Assessment (quoted by Hazeltine and Bull in [11]) gives a slightly different definition for Appropriate Technology, stating that it should be "small scale, energy efficient, environmentally sound, labor-intensive and controlled by the local community". Although this seems reasonable, it assumes that "Appropriate Technology" is in the context of the South. Hazeltine and Bull [11] add the Intermediate Technology Development Group's suggestion that "the technology must … be simple enough to be maintained by the people using it". This, with Dunn's definitions, show that Appropriate Technology goes further – it is technology that is appropriate to the context in which it is to be used, whatever and wherever that context may be. It is noteworthy that Dunn's criteria do not per se define the word "local", and that what might therefore be considered to be "local" will change depending on the specific situation. In rural Rwanda, for example, "local" might extend to a 5 mile walking-distance. Closer to Kigali, the capital of Rwanda, 10 or 15 miles might be local, where local buses and minibus-taxis become available. In the UK, "local" might include a 50 mile radius for commuting to work, but may also include the wider EU for material resources, or perhaps the world for financial resources. On this basis, any technology, in any situation, can be "Appropriate" if in that specific situation Dunn's criteria are met and the technology is relevant. Returning to Hazeltine and Bull's statement mentioned above: "One must look at what one is trying to accomplish, what expertise and resource are available, and what unintended consequences may ensue" [11]. This is just as true for the North as it is for the South but, as one of Dunn's resources, it also links technology into Sustainable Development.

Technology, however, is not the only factor to be considered, based on Dunn's aims and criteria. For his technology to be Appropriate, he requires the use of renewable resources and understanding of local culture and finance. These match the so-called "Three Pillars of Sustainable Development", namely environment, society and economy. The pillars are often quoted as three legs of a stool that together support the Sustainable Development seat as shown in Figure 2.

Figure 2. The Three Pillars of Sustainable Development

Continuing the analogy, it might be suggested that technology is the ground on which the stool rests, as in Figure 3. If the ground is not considered, the stool could be placed on an uneven or sloping surface, which does not stop the stool being used, but makes it less attractive or comfortable for use. In ensuring that the technology is Appropriate, a suitable foundation for that particular stool has been found and will support the stool throughout its lifetime. Any product, be it PVP or carpet, must be considered in the context of these three pillars together with Appropriate Technology.

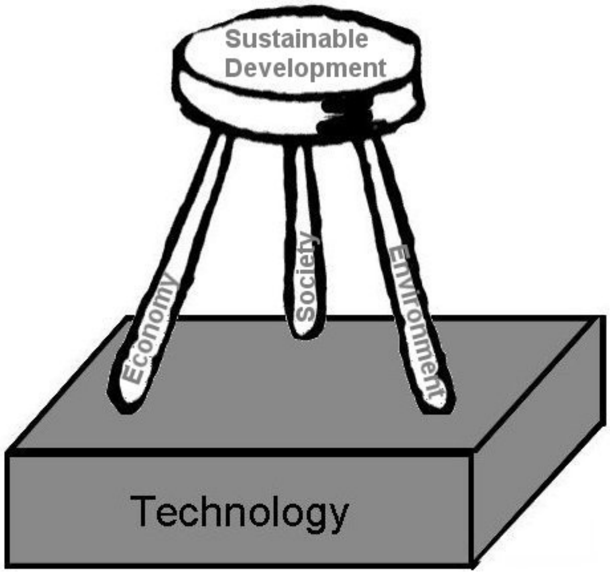

Figure 3. The Three Pillars of Sustainable Development with their Foundation

It would seem that Sustainable Development and Appropriate Technology have much in common, the latter being one medium by which the former can be carried out. Where DFSD is being included as part of a design process, it must therefore go beyond simply considering environmental impact or even all three pillars, and must take into account the foundation of sustainable development: the technology employed. A true DFSD process requires an understanding of the local skills, resources and society as well as the part that the particular technology is going to play in supporting each of these.

3 PVP TECHNOLOGY

On the basis of the previous section it is evident that DFSD requires an assessment of the appropriateness of each of the technologies suggested, in the light of local resources, culture and so on. The technology of a generic pumping system can be discussed in two parts: firstly the source of power and secondly the pump itself. Taking a step backwards from PV, the power for pumping may be provided mechanically: through human or animal energy; directly from a rotating wind turbine; or indirectly from a thermal source (solar, biomass etc.) through a sterling engine. Alternatively, the power may be electrical, from batteries, the grid, a wind electric generator or a diesel generator, any of which would drive a motor and hence the pumping mechanism. The pumping mechanism also presents a number of different choices, including centrifugal and reciprocating pumps.

PVP systems

In order to assess whether or not PVP can be deemed to be a potentially "appropriate" technology the PVP system – an example of which can be seen in Figure 4 – must first be described. A PV panel can be used to power a DC motor; this may be connected directly to a centrifugal pump which provides the water to a storage tank, decoupling the availability of sun from the use of water and creating an "energy storage device" more environmentally benign than a battery. A number of technology related factors complicate this situation, as described in previous papers [17, 18]. Manufacturers may choose to use AC rather than DC motors, for consistency with other product lines or to lower their costs, thereby requiring an inverter in the system. Also, if the motor characteristics do not match the input from the panels, a "maximum power point tracker" (MPPT) may be introduced, normally combined with the inverter to ensure maximum use of the expensive solar panel (shown as "controller" in Figure 4). The centrifugal pump is very effective, but only when close to its design head and flow rate. Away from these criteria (e.g. when the water level in a well rises because of local rainfall), performance drops off rapidly. Much broader performance may be possible from certain reciprocating pumps [17] but the motor's rotational motion must somehow be converted to the pump's linear motion. Equally, the pump/motor system may be surface mounted – as can be seen in Figure 1 – rather than the submersible system of Figure 4. The "basic theory" quickly becomes a complicated practice, threatening the sustainability of any system in the South.

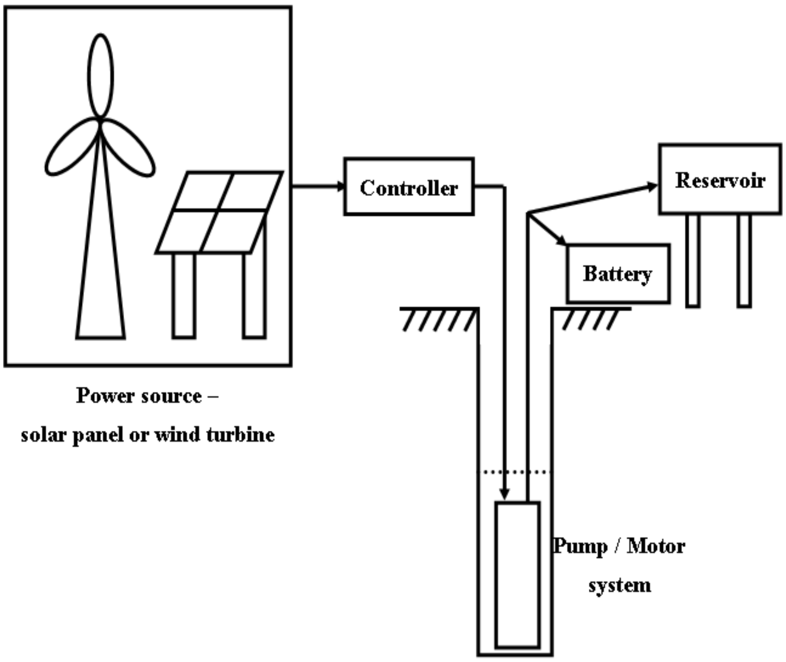

Figure 4. Example of PV or Wind Electric Pumping System

PVPs and Appropriate Technology

Bearing in mind such complexity, Hazeltine and Bull [11] ask the question "When are photovoltaics appropriate?". They base their answer around the statement "They make sense when the alternatives, such as power lines or batteries in calculators, are expensive or a nuisance" – typically in rural, off-grid areas. They further comment "Photovoltaics seem to be an ideal source – reliable, quiet, pollution free, land conserving and locally controllable", whilst recognising that they "cannot be constructed by an amateur or even a good machinist" and "costs … inhibit widespread use of PVs".

Although a PV panel, with no moving parts, is infinitely less complex than a diesel generator, and can easily play a role in water provision, the reality is that PVPs are commonly considered to be too expensive, too complicated and too unreliable for "Appropriate Technology". "Village Level Operation and Maintenance" [19], desired by some agencies working in the South, is sometimes thought to be impossible for PVPs, particularly in comparison to the simple handpump. Consequently, many suggest that PVPs are inappropriate for most countries in the South. Conversely, diesel-powered pumps are well used, well understood and are thought to fall within Appropriate Technology. Should this be the case? To answer this, Dunn's aims for development must be revisited. Any improvement in a water supply will "improve the quality of life of the people"; not all will "maximise the use of renewable resources". Creating "work places where the people now live" is often recognised by project managers, together with the use of local NGOs instead of ex-pats. Thus the key to satisfying Dunn is his second aim – "maximise the use of renewable resources". There are many potential solutions, including the use of human or livestock energy, but PVPs can also be seen to meet this aim whilst diesel pumps do not.

Going beyond Dunn's aims, it is now his technology criteria (a) – (e) that should be inspected. In attempting to meet each criterion, it is more difficult for PVPs to be thought of as "appropriate". Rather than just dropping a pump down a borehole, the entire project philosophy must be examined. The ideal PVP would not only meet the requirements of "Village Level Operation and Maintenance", but also "Village Level of Manufacture" ("VLOMa") if local skills are best to be employed. Should this be possible, many of the other criteria fall into place.

One could imagine a simple PV pump, using the technology required to maintain a car. It would use DC electricity from the solar panels, with no complicated electronics, and would have easily accessible/maintainable parts. Whilst the pump may have low efficiency, this drawback may be outweighed by the gains made through self-manufacture. Despite such a pump currently being under investigation at Durham University [20], most PVPs do not meet this condition; instead they use complicated electronics that require a level of technical ability, should things go wrong, far higher than that usually available in the South. VLOMa, for these systems, is likely to be impossible, preventing Dunn's criteria (a) – (c) from being met during the majority of a pump's life.

In addition to the pump system itself, most countries in the South do not have the skills and facilities to manufacture photovoltaic panels (although China, India and South Africa have now developed their own facilities). Whilst not ideal, this situation does not immediately negate Dunn's criteria. Maintenance for the panels does not require the same technical knowledge as manufacture – as long as this is possible, criteria (a) – (c) can still be met. Returning to the simple pump that has been suggested above, this would still need to be manufactured and maintained locally which is obviously dependent on the location in which the PVP is to be applied.

PVPs and Engineering Design

The design of the PVP system, with DFSD as a part of the process, now becomes an exercise in trade-offs, as suggested in the introduction. In the context of the PVP there are a number of competing – and contradictory – requirements of which Sustainable Development is just one. Considering a few of these requirements – cost, reliability, efficiency – quickly develops a list of design contradictions:

- The inclusion of an inverter in the system lowers the system cost through the use of cheap AC motors. This is also likely to lower the inventory of the company through standardisation of motors. However, inverters have been shown to be the key cause of PVP failure (see [21] for further discussion) and product quality can be seriously compromised by their use.
- The use of an MPPT increases the available power output from the panel, increasing system efficiency, but adds cost and potential reliability issues similar to those of the inverter.
- Direct connection between the PV panel and the motor (without inverter or MPPT) reduces the efficiency of the overall system but increases its reliability. In many places, the reliability of the safe water source can be a key health issue, as discussed in [17].

This (non-exhaustive) list demonstrates some of the standard engineering design issues involved with a PVP. Now bringing in DFSD, one might ask the question "how important *is* Sustainable Development as a design criterion?" and then take the view that it is the crucial criterion above all others. Unfortunately that immediately provides its own contradictions. For example, a highly efficient pump system requires less resources external to the immediate locality in that it requires less PV; however, the manufacture of a highly efficient pump system would require external personnel resources. Lagerstedt [22] summarises this in stating that "… during requirement evaluation, environmental demands have to coexist with all other requirements and constraints. Design solutions must seek a balance between all the competing requirements".

Looking at efficiency, in this context it can be defined as the water output in m^4/day (head x volume/day) per solar radiation input (kWh/day). However, for any system based on similar renewable resources, the latter might not be thought to be crucial as the solar radiation input – the "fuel" – is free!

If insufficient output is available, more PV panels can be purchased to provide that output. That comes at a financial cost, however, so an often more important figure is the total system cost per output – i.e. £/m[4]. This acknowledges the current high cost of solar PV panels and their cost within the system, without penalising them for their efficiency. The only time when efficiency might become an issue is where a limited area is available (such as on a roof) and maximum output might be required per area; it is unlikely that this would be an issue for most relevant sites in the South. The design trade-off for a system that makes use of a renewable resource is far more complicated, therefore, than that for a traditional non-renewable (and perhaps non-sustainable) system. In the case discussed here the sub-system efficiency from PV ***output*** to water output is typically taken to be of extreme importance (thereby requiring an expensive and complicated MPPT) to minimise the amount of costly PV required. As the cost of PV goes down rapidly, which is an expected output from the continued research into new PV materials and manufacturing methods, the system cost-balance will change and the trade-off will equally change.

Sustainable PVP systems

In the "North", neither the manufacture nor the reliability of PVPs is a concern: the electronics are thought of as no less reliable than many electronic components and the after-sales service is sufficiently developed should any problems occur. In countries where the PC is the norm, why should a solar powered water pump be inappropriate? However, the last statement is also true for many developing countries. The Kigali Institute of Science, Technology (KIST) in Rwanda, for example, teaches courses in the maintenance and repairs of computers, yet many areas of Rwanda have no safe water, sanitation or electricity. The PC is not limited to the North, and if countries in the South can support such a high-technology industry, is it not reasonable that they should be able to provide sufficient support structure to allow PVPs to be used?

A very small country such as Rwanda, with its centrally located capital (Kigali), may be ideal as a starting point; the entire country being easily traversed by car in a day. Pumps could be manufactured in the capital and distributed quickly and easily throughout Rwanda. Spares and repairs networks could be set up without problems, any major repairs carried out in Kigali as necessary. Rwanda's next door neighbour, the Democratic Republic of Congo, is a very different matter, however, simply due to its size – providing any support service within this country could prove very difficult because of the vast distances between locations.

Typical design methodologies such as Design for Assembly, or for Manufacture, often seek to standardise components and systems, driving down inventory and reducing costs. This might imply attempting to standardise on pumps across (for example) Africa. However, with such differences existing between even neighbouring countries, it would seem that attempts to standardise any type of pump – whether a particular type of handpump, or even just a general power source – would be impossible. Different national or even local capabilities will require different types of pump that can be both manufactured and maintained locally. Ignoring this in the pursuit of higher technology, or even standardised technology, risks that technology proving inappropriate, and thereby becoming unsustainable. Pump Aid, promoting the use of the Rope and Washer Pump, makes the following assertion [23]:

> *Technology driven projects can fall down in their failure to recognise an appropriate mode of operation when there is transfer from one country or cultural context to another. While standardisation of design is clearly desirable, a rush to standardise can lead to perpetuation of inappropriate design choices. This is indeed an argument that has dogged handpump and users and demonstrates problems with assuming that a technology that has proved sustainable in one region will therefore be sustainable in another.*

The same argument is directly applicable to PVPs and becomes a fundamental tenet of DFSD – the demonstration that any system is sustainable in one region does not permit the assumption that it is equally sustainable in another. Every situation is different, with a different definition of what is "local", what is "Appropriate" and consequently what is "sustainable".

4 SUSTAINABILITY, SERVICES AND CELL PHONES

One further aspect remains to be considered. Dunn states that "A project that does not fit, educationally and organizationally, into the environment, will be an economic failure and a cause of disruption" [15]. This implies a further aspect of sustainability, as suggested on page 6: that of the project philosophy itself. The lack of long term success of any particular PVP project can have a direct impact on a community. There is an immediate issue regarding health (see [17]), but also a failure of trust in the technology may result, along with the potential collapse of any business and economic opportunities reliant on the water supply, such as market crops. The sustainability of any project is key to the health and development of the reliant community. The question, therefore, is how to ensure the sustainability of these projects and this must go beyond technological issues and reliability. Instead it must go into why people would want a PVP system to be maintained and what methodologies could be used to ensure their sustainability.

As an example, on visiting KIST in Rwanda, the author was astounded at the apparent widespread use of cell phones in a country not renowned for its technological forwardness. Much of the country, albeit small, has cell phone coverage. Whilst not widespread in comparison to the UK, the prevalence of cell phones in Rwanda is due to their convenience for receiving calls and the lack of landline infrastructure. For outgoing calls users tend to revert to public telephones as this is cheaper. Cell phones are also well used in Ethiopia – to the extent that supplies of SIM cards and handsets are extremely low, and the telecommunications office has taken steps to curtail a "sell on" market. This time, however, it is due to their value as a status symbol, together with the convenience and reliability in comparison to landlines.

The UK market for cell phones is perhaps an "advanced" example of what has happened in Ethiopia. The cell phone is a symbol of status, an item of fashion. When cell phones first entered the market, simply owning one proved your status – they could be thought of as a "delighter", to use the language of the Kano model [24]. Now, however, they as products have become "must haves", with only the latest model, the smallest, the lightest, the most advanced being "delighters". Whilst the cell phone market itself may be sustainable, an individual telephone is not, as technology moves forward – within a matter of weeks it is outdated and the owner pines for a new one. Similarly in the South it is to be expected that, as cell phone ownership becomes more "the norm" and less itself a symbol of status, a symbol of ones' modernity and being up-to-date, the life of any handset will be reduced.

To extend this example to PV pumps, Kaunmuang et al. [25] described the locating of a PVP within the village headman's compound – effectively as a status symbol or demonstration that he was "technologically modern". As PV and PVP systems become more widespread or more known, they are no longer the "latest thing" and so newness and status cannot be relied upon as drivers for purchase. Relying on the apparent "sexiness" of a PVP (without mentioning the considerable cost) is not going to drive an individual consumer to purchase and maintain a system.

A true DFSD process may go beyond thinking of supplying a "product" and may instead investigate the "provision of services" methodology sometimes proposed to promote sustainability. Suggested by von Weizsäcker et al's seminal "Factor Four" [26] and further elucidated by Hawken et al [27], a "service and flow economy" is advocated, requiring "a fundamental change in the relationship between producer and consumer, a shift from an economy of goods and purchases to one of service and flow" [27]. In many instances this suggests a complete paradigm shift, for example carpeting as a service rather than a product as espoused by McDonough and Braungart [28]. Mont [29] states that "A new trend of product-service systems that minimise environmental impacts of both production and consumption is emerging", noting that "appropriate social structures are required when designing new product-service systems. They consist of infrastructure, human structures and organisational layout, and are needed for the establishment and effective functioning of product-service systems."

At first glance, the idea of a PVP as a service may seem as surprising as the provision of a carpet as a service. Once the idea is investigated, however, it may seem less startling. Consider the Solar Home System (SHS) where PV may provide electricity for lighting, for example. A consumer purchasing an SHS is the exact opposite to the typical situation – services are the norm where electricity is concerned! Rarely do consumers go shopping for an oil fired power station – they buy the service of electricity from the grid. Similarly, at least in the North, most urban domestic consumers do not have their own water source – they pay for the service of water provision from a local or national company. It seems strange, then, that individual or community ownership of water provision systems (whether powered by hand, PV or diesel) should be expected when it is extremely rare in the North. This is not to attempt to impose "capitalistic" values on the South, but simply to recognise that most people do not want PV on their roofs, many do not want electricity necessarily. They want (with emphasis added) "the <u>services</u> that energy provides, not fuel or electricity" [30]; in the case of the PVP, the service they want is a clean, reliable supply of water and this is therefore, according to Dunn's criterion (e), what should be supplied. According to Roegner et al [31] (quoted in [32]), "a true solution is defined and designed around a customer's need, not around an attempt to find a new use for a supplier's current products". Thus the best means of providing a service can only be decided by deciding what is both Appropriate and Sustainable for the particular community, not by looking at existing products or systems.

Where PV has been provided as a service in the South, outcomes have been positive. Ellegård and Nordström [33] say that the "Energy Service Company" (ESCO) concept has been popular precisely because it is an electricity service that is being sold. "The … equipment remains the property of the Energy Service Company", whereas "The client pays for the services provided" rather than having to purchase the capital intensive equipment themselves. In Lao, the ESCO concept goes beyond PV systems – ESCO companies "offer a choice of electricity supply technology, so that there is a solution for each village" [34]. This choice includes micro-hydro systems, and thus the most relevant (or appropriate) technology can be chosen for each village.

Just as electricity can be provided as a service, with PV as the technology, so water can equally be provided as a service using PVPs as the technology. Münger [35] reports that in Mauritania, where equipment is provided by Government and managed by private water suppliers, there were no panel failures and only 1.5% pump failures per year over 4 years. This contrasts strongly with other PVP projects, such as those discussed by Short and Oldach [21] where a failure rate of 18% was common.

Returning to the comparison with the cell phone, it is possible to argue that cell phone technology has been provided as a service – hand sets are relatively cheap, whilst the associated call charges pay many times over for their use. Certainly in the North, where handsets are updated free of charge by many companies in exchange for a long-term contract, owners are paying for a telecommunications service, rather than any particular product. Perhaps it is this service, rather than the fashion statement or status symbol that will make the cell phone sustainable for many people. Consequently it would seem that a design process incorporating DFSD cannot ignore the possibility of the fundamental change from selling products to providing services.

5 DISCUSSION AND CONCLUSION

The pressure to include DFSD as part of a "superior design process" is rapidly increasing, with legislation backing up governmental targets. Whilst altruistic or legalistic companies may therefore be pushing forward with DFSD, it is not always clear that their processes recognise the true depth – and potential – of DFSD. Indeed, most companies have not recognised the commercial opportunity presented by using DFSD processes; the DTI report "Sustainability and Business Competitiveness" [36] notes that "A business with strong corporate social responsibility will often be more successful in generating Economic Value Added".

A number of design methodologies currently exist under the heading "Design for Sustainable Development" or similar. In investigating some of the issues under such a heading, this paper has shown just how broad DFSD really is. DFSD is not limited by technology or location – instead it draws on that location to define what technology is and is not sustainable.

The use of Dunn's criteria and aims to ensure the appropriateness of technology, together with the 3 pillars of sustainable development, has allowed a deep understanding of the area of engineering that a DFSD process must address. This is not to say that Sustainable Development concerns are the "key" areas within the design process – they are simply one of the constraints on an engineering product that must be traded off against other constraints, such as safety, cost and maintenance. Just as Boothroyd's Design for Assembly (one component performs many functions) contradicts Pahl and Beitz's "Principle of the Division of Tasks" [37] (one component performs one function), so DFSD sometimes contradicts other design principles such as "standardise for all locations" and "use the cheapest". Indeed, it can sometimes contradict itself, as demonstrated in section 3.

The use of the solar powered water pump as an example of DFSD has demonstrated many of these contradictions and associated issues. It highlights the requirement to consider location and thence the importance of reliability in relation to the maintenance support that is or is not available "locally". Simply because a product has been shown to be sustainable in one region does not automatically make it sustainable elsewhere. Every situation is different and that fact must be included within DFSD. That said, even if a PVP is in a situation where it is not deemed to be Appropriate Technology, it does not necessarily make the three-legged stool of Sustainable Development fall over – it just makes it more

likely. One factor that may help ensure sustainability is the possibility of providing services rather than products alone, and this should also be factored into the DFSD process.
In a final reference to the analogy, the cell phone has become particularly popular for one predominant reason – its convenience in comparison to the alternative of the landline. For DFSD to have been satisfied, the same must be true for PVPs – their convenience, in many places, over the grid and over the diesel engine that needs regular maintenance and fuel. DFSD processes must therefore start with a realistic understanding of what is required by the user of the product or service. Sustainability and "appropriateness" for any given situation depends on whether local people have been given what they want.
This paper has investigated the reality of the PVP and its technology, and used it as an example to demonstrate the complexity of the DFSD process. The provision of water should not be "technology driven", but should "satisfy local wishes and needs", as required by Dunn. If this is the starting point in the South, it should equally be the starting place for a design process in the North. Only once this lesson is learned can Design for Sustainable Development provide a truly sustainable design process – one that meets the needs and aspirations of the present alongside those of the future.

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